PHYSICAL GEOLOGY

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Physical Geology H5P

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Acknowledgments

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This project would not be possible without the generosity of many individuals and organizations who shared their work with a Creative Commons license or under other open licensing terms. The following is a list of valuable image resources, as much as it is an acknowledgement of contributions:

Roger Weller has made available thousands of his high-quality rock and mineral photographs through his website hosted by Cochise College, and granted permission for their non-commercial educational use. His photos have been used extensively throughout this project. Roger's usage stipulation has led to thoughtful discussions about what the appropriate way is to license derivative materials that make use of non Creative-Commons content. I have concluded that the best way to ensure that his wishes are respected is to license materials I make with his photographs as CC BY-NC-SA. This permits free sharing and remixing, but stipulates no commercial use, and that all derivative works must be shared with a non-commercial license.

James St. John is a geologist and paleontologist who has contributed (as of August 2021) 80,190 high-quality geology-related photographs to the photo-sharing website Flickr. His photographs cover a wide range of rocks and minerals, and rarely has there been an image that I needed but couldn't find in his work. His Flickr account is remarkable for the abundance and quality of photographs, but also because he includes detailed descriptions of his images, making it possible for me to verify that an image is what I think it is, and gather useful background information. He has shared his images with a CC BY license, which I appreciate greatly because it allows me to combine them with content having more restrictive licenses. You can find his teaching website here, and video footage from his Yellowstone geyser project here.

The **U. S. Geological Survey** has contributed innumerable images to the public domain. The Hawaiian Volcano Observatory in particular is my go-to source for both the latest in volcano photos, and for fascinating historical images. Data and images from the USGS Earthquake Hazards Program Latest Earthquakes map have been invaluable.

I have used **NASA** images for views of Earth as much as I have for views of space and other planets. It is truly remarkable that in spite of the vast resources and expertise needed to acquire these photographs, they are free to view, use, and learn from.

Among the many teaching resources offered by **IRIS** (Incorporated Research Institutions for Seismology) are beautifully designed images for explaining earthquakes and seismology.

When all other sources failed, the odds were good that Robert Lavinsky (www.iRocks.com), Mike Norton, or Michael Rygel had contributed exactly the right photograph to Wikimedia Commons.

CHAPTER OVERVIEW

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1.1: What Is Geology?

The Study of Rocks?

Imagine that someone has just asked you what **geology** is. If your answer is, “It’s the study of rocks,” then you’re in for a surprise! While rocks are important to geology, some geologists don’t study rocks at all. Geologists might study water, climate, organisms in extreme environments, or environments where rocks might form in the future.

If your answer is “It’s the study of Earth,” you’d be getting closer. Geologists *do* study Earth—its interior and its exterior surface, the rocks and other materials around us, and the processes that formed those materials. They also study how Earth has changed over the vast time-span of its history, and how it might change in the future.

Even so, you’d *still* be missing the work done by geologists who study other planets or solid non-planetary objects in space. Perhaps reading this chapter will be the start to your career as the head geologist on a Mars survey crew locating water resources for a new colony…

Earth’s Geology Helps Us Understand Ancient Mars

These photographs are of the same type of rock, but one is on Mars (left) and the other is on Earth (right). On Earth this type of rock is formed when rapidly moving water carries broken pieces of rock, smooths them off, then drops them on a stream bed. By knowing how this rock forms on Earth, we can tell that Mars also had water flowing rapidly over its surface at some time in its history.

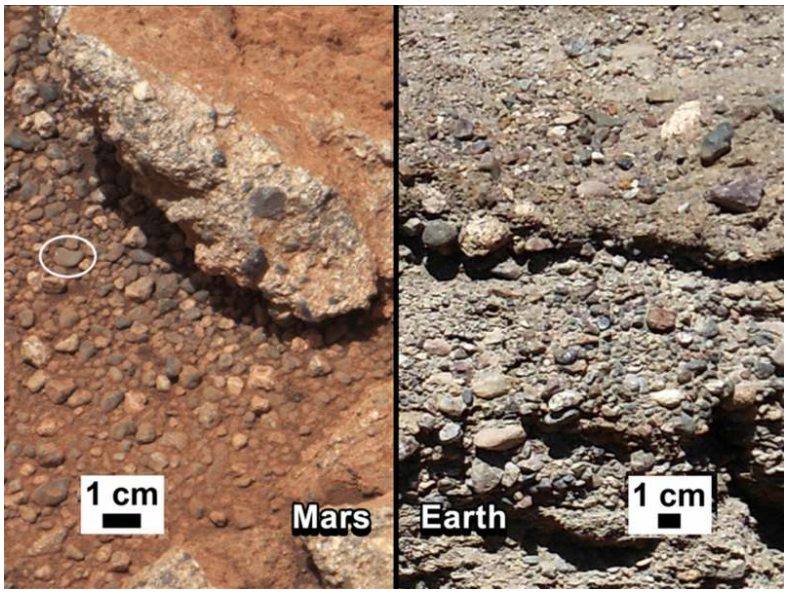

Figure 1.2 Left: Link outcrop on Mars photographed on 2 September 2012. Right: A similar outcrop in the Northwest Territories. *Source: NASA/JPL-Caltech/MSSS and PSI (2012). Public Domain. View source.*

Geology Is a Science

Geological questions are investigated by collecting evidence, hypothesizing about what that evidence could mean, and finding ways to test whether those ideas make sense or not. Geological science is done with the same rigour as any other science, and this means that a lot of creativity is sometimes required to figure out how to test hypotheses. For instance, how do you test a hypothesis about what Earth was like 3 billion years ago? Some geoscientists test such hypotheses by trying to find modern-day environments that are similar to ancient Earth environments.

Geology is an interdisciplinary science. Geologists must understand and apply other sciences—physics, chemistry, biology, mathematics, astronomy, and more—in their work. Geoscientists often consult with or work with scientists in other disciplines.

An aspect of geology that is unlike most of the other sciences is the role played by the vastness of time. When geologists study the evidence around them, they are often observing the results of events that took place thousands, millions, and even billions of years in the past, and which may still be ongoing. Geologists study not only processes that happened long ago, but processes that happen

at incredibly slowly. Changes in the shape of Earth's surface might only happen at rates of mm to cm per year, but because of the amount of time available, tiny changes can result in expansive oceans forming, or entire mountain ranges being worn away.

Geological Time in the Canadian Rocky Mountains

The photographs below show changes that happened in the blink of an eye, geologically speaking. At the same time, they also illustrate the vastness of geological time.

The past 100 years. On the right of both photos is Rearguard Mountain, which is a few kilometres northeast of Mount Robson. Mount Robson is the tallest peak in the Canadian Rockies, at 3,954 m. The large glacier in the middle of the photo is the Robson Glacier. The river flowing from Robson Glacier drains into Berg Lake in the bottom right. The photo on the right was taken around 1908 by the Canadian geologist and artist Arthur Philemon Coleman, and gives an indication of how much the glacier has receded in the last hundred years due to rapid climate change.

The past two million years. This area—like much of Canada—has been covered repeatedly by glaciers over the past 2 million years. Those glaciers scoured away rocks to form the valley on the left.

500 million years ago. The rocks making up the mountains formed in ocean water over 500 million years ago. A few hundred million years later, a great collision between Earth's tectonic plates pushed those rocks east for 10s to 100s of km, and 1000s of m upward.

Figure 1.3 Rearguard Mountain and Robson Glacier in Mount Robson Provincial Park, BC. Left: Robson Glacier today, retreating up the valley. Right: Robson Glacier circa 1908. *Sources: Left- Karla Panchuk (2017) CC BY-SA 4.0 with photo by Steven Earle (2015) CC BY 4.0. View source. Right: A.P. Coleman (c. 1908) Public Domain. Click the image for more attributions.*

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1.2: Why Study Earth?

Earth is our home, and by studying geology we can learn how to live here safely, and how to use the resources we need in a sustainable way:

- We can learn to minimize our risks from earthquakes, volcanoes, slope failures, and damaging storms.
- We can study rocks and the fossils they contain to understand the evolution of our environment and the life within it.
- We can learn how and why Earth's climate changed in the past, and use that knowledge to understand both natural and human-caused climate change..
- We can measure how human activities have altered the environment, and learn how to prevent and sometimes repair the damage.
- We rely on Earth for resources such as soil, water, metals, industrial minerals, and energy, and we need to know how to find these resources and exploit them sustainably.

Arguably, studying Earth is more important than ever. Moving away from fossil fuels as an energy source means *more* extraction of mineral resources, not less, because those resources are needed to build clean-energy technologies, such as batteries. It's essential that we learn how to do so without repeating the mistakes of the past.

Studying Earth is also important for helping to keep people safe as the climate changes. Even people who don't necessarily plan to be geologists—e.g., policy makers, community leaders, and the general public—can benefit from understanding how their environment works.

Spotting Everyday Hazards

Look at the slides below and see if you can spot a common hazard related to how Earth's surface changes over time, but that humans can alleviate by planning ahead.

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1.3: What Do Geologists Do?

Figure 1.4 Geologists at work on the island of Spitsbergen, part of the Svalbard archipelago. The islands are located in the Arctic Ocean north of Norway. *Source: Gus MacLeod (2007) CC BY-NC-ND 2.0. View source.*

Geologists do a lot of different things. Many of the jobs are the things you would expect:

- Geologists work in the resource industry, including mineral exploration and mining, and exploring for and extracting sources of energy.
- They do hazard assessment and mitigation (e.g., assessment of risks from slope failures, earthquakes, and volcanic eruptions).
- They study the nature of the subsurface for construction projects such as highways, tunnels, and bridges.
- They use information about the subsurface for water supply planning, development, and management, and to decide how best to contain contaminants from waste.

Geologists also do the research that makes practical applications of geology possible. Some geologists spend their summers trekking through the wilderness to make maps of the rocks in a particular location, and collect clues about the geological processes that occurred there.

Some geologists work in laboratories analyzing the chemical and physical properties of rocks to understand how the rocks will behave when forces act on them, or when water flows through them. Some geologists specialize in inventing ways to use complex instruments to make these measurements.

Geologists study fossils to understand ancient animals and environments, and go to extreme environments to understand how life might have originated on Earth. Some geologists help NASA understand the data they receive from objects in space.

Geological work can be done indoors in offices and labs, but some people are attracted to geology because they like to be outdoors. Many geological opportunities involve fieldwork in places that are as amazing to see as they are interesting to study. Sometimes these are locations where few people have ever set foot, and where few ever will again.

Living with a Volcano

Figure 1.5 Ash plume from the eruption of La Soufrière on the island of St. Vincent on 9 April, 2021. In the Red Zone near the volcano, risk of life-threatening volcanic hazards is highest. An evacuation was ordered on 8 April, 2021. *Source: Karla Panchuk (2021) CC BY-SA. Photograph by Lauren Dauphin, NASA Earth Observatory. Click here for more attributions.*

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1.4: We Study Earth Using the Scientific Method

Science Is a Process

Some people consider science to be a set of facts about nature, but a better description of science is that it's a means of collecting those facts in as reliable a way as possible. Carl Sagan, an astronomer and author, put it this way:

> *Science is more than a body of knowledge. It is a way of thinking; a way of skeptically interrogating the universe with a fine understanding of human fallibility.* (The Charlie Rose Show, 1996)

The understanding of human fallibility that Sagan refers to is the awareness that human brains take shortcuts in reasoning. Sometimes we're conscious of these shortcuts, but other times we're unaware. An example would be the tendency to have more confidence in a fact that is repeated by multiple sources than in a fact stated only once. If you do an Internet search and see the same fact repeated on many websites, it might seem that the fact has been independently confirmed by many people. However, it could simply be that everyone used the same Wikipedia article for their research. The **scientific method** is a way to reduce the likelihood that errors in reasoning will lead to flawed conclusions.

In its most basic form, the scientific method involves formulating an idea about how the world works—a **hypothesis**—and then finding a way to test it to see if it's actually true, and should be accepted.

The term **theory** is often used in everyday language as a synonym for hypothesis, but that's not what a scientist means when they talk about a theory. What they're referring to is a hypothesis that has been tested over and over again, and passed every single test. Saying that an idea is a hypothesis is like suggesting, "Maybe the world works this way." Saying that an idea is a theory is like concluding, "It's extremely unlikely that the world works in a way other than this."

Another term commonly used to describe a scientific idea of great certainty is **law**. But don't confuse a law with a theory. Whereas theories are explanations of phenomena, laws are descriptions that apply under specific circumstances. For example, the law of conservation of mass tells us that mass is never lost or gained in physical interactions. An object might break into two, but the total mass of the two parts is the same as the mass of the original. The law doesn't explain *why* mass works that way, but it is a reliable rule to use when doing physics calculations.

Theory, Hypothesis, or Law?

An Example of the Scientific Method at Work

Imagine a field trip to the stream shown in Figure 1.6. Notice that the rocks in and along the stream are rounded off rather than having sharp edges. We might hypothesize that the rocks were rounded because as the stream carried them, they crashed into each other and pieces broke off.

Figure 1.6 Hypothesizing about the origin of round rocks in a stream. *Source: Steven Earle (2015) CC BY 4.0 view source*

If that hypothesis is correct, then the further we go downstream, the rounder and smaller the rocks should be. Going upstream we should find that the rocks are more angular and larger. If we were patient we could also test the hypothesis by marking specific rocks and then checking back to see if those rocks have become smaller and more rounded as they moved downstream.

If the predictions turn out to be correct, we must still be careful about how much certainty to attach to our hypothesis. Although our hypothesis might seem to us to be the only reasonable explanation, someone could argue that we have the mechanism wrong, and the rocks weren't rounded by bumping into each other.

If our experiment didn't specifically check for the mechanism (e.g., by looking to see if chips fall off the rocks and the rocks are made smoother) then we would have to acknowledge the possibility. We needn't abandon the hypothesis as a useful tool for making predictions, but it is necessary to be open to the possibility that other things might be going on. If someone demonstrates conclusively that our hypothesis is wrong, then we have to discard the hypothesis and come up with a better one.

A good hypothesis is testable. Someone might argue that an extraterrestrial organization creates rounded rocks and places them in streams when nobody is looking. There's no practical way to test this hypothesis to confirm it, and there's no way to prove it false. Even if we never see aliens at work, we still can't say they haven't been, because according to the hypothesis they only work when people aren't looking. Compare this to our original hypothesis which allows us to make testable predictions such as rocks getting smaller and rounder downstream. Our original hypothesis gives us a way to see how realistic it is, whereas the alien hypothesis gives us no way to know if it makes sense or not.

Lucky Socks Science

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